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Development of coherent EUV source for EUV mask metrology

Dong Gun Lee^{1*}, Jong Gul Doh¹, Hwan-Seok Seo¹, Buyeob Yoo², Jonglip Choi², Jinho Ahn³, Seong-Sue Kim¹, and Han-Ku Cho¹

¹Semiconductor R&D Center, Samsung Electronics Co., Ltd.

²Fine Semitech Co., Ltd.

³Department of materials Science and Engineering, Hanyang University

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- Summary

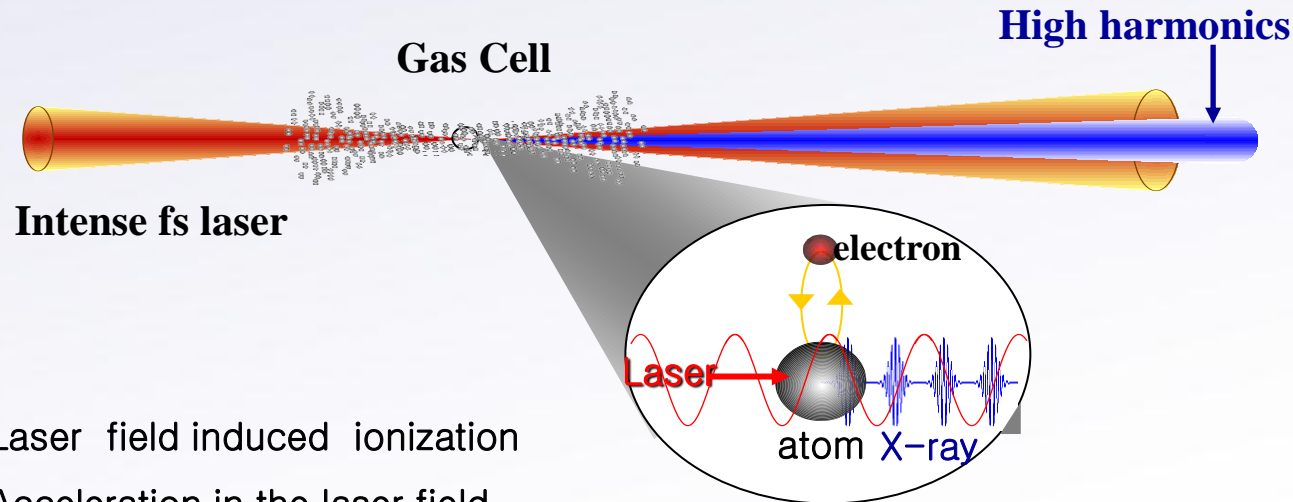
EUV Metrology Source

Type	Incoherent EUV source (=lamp-like source)	Coherent EUV source (=laser-like source)
method	LPP & DPP source	High-Order Harmonics & x-ray laser
Application	<ul style="list-style-type: none">•Blank& Pattern Mask Inspection•EUV AIMS•Reflectance measurement	<ul style="list-style-type: none">•Interferometer•Interference Lithography•Phase measurement•Coherent Scattering Microscopy (CSM)

- CSM* as an EUV scatterometry could offer the advantages of high throughput and superior repeatability in actinic CD-metrology applications

**EUVL symposium 2008, Donggun Lee., et al*

High-Order Harmonic Generation



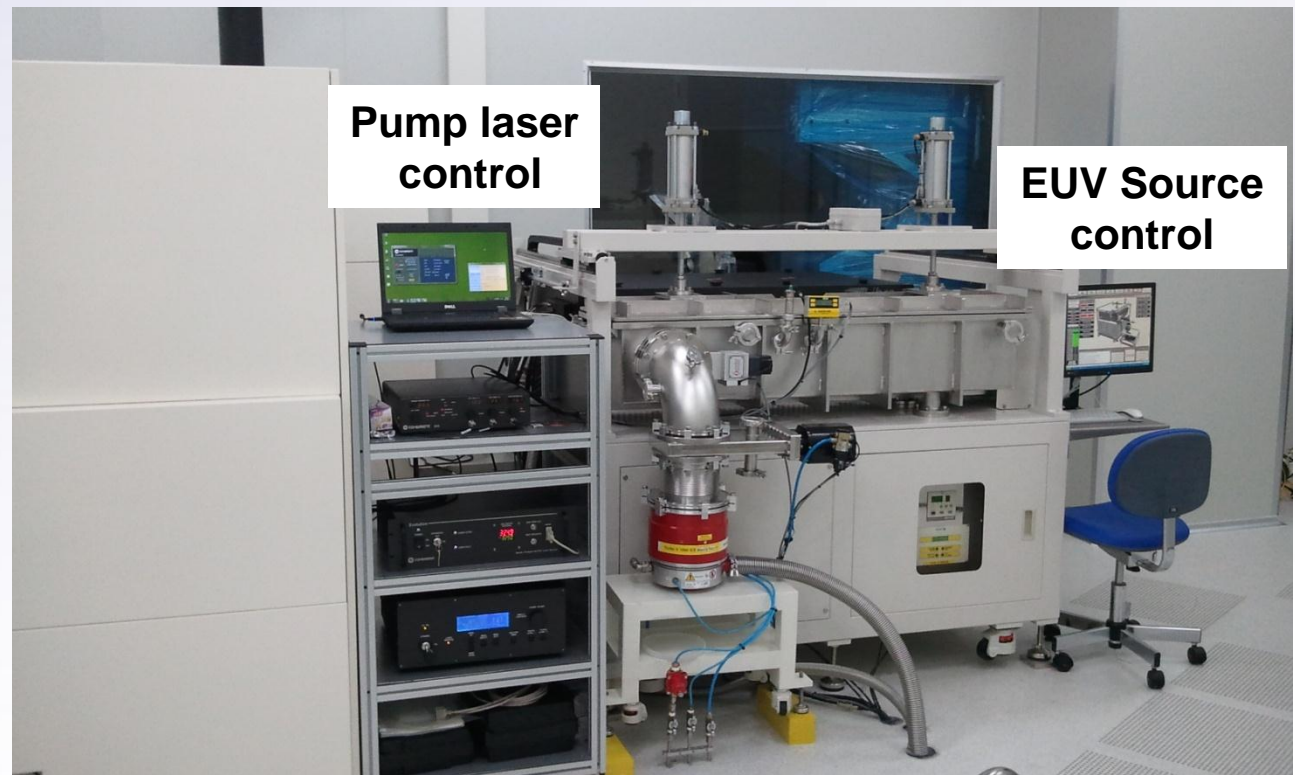
- (1) Laser field induced ionization
- (2) Acceleration in the laser field
- (3) Recombination to it's mother atom

- The high-order harmonics are emitted in a coherent laser-like beam
- Fully spatially coherent 13.5-nm harmonic beam(59th of 800-nm pump laser beam) is best EUV source for CSM applications

Commercial Coherent EUV Source From FST

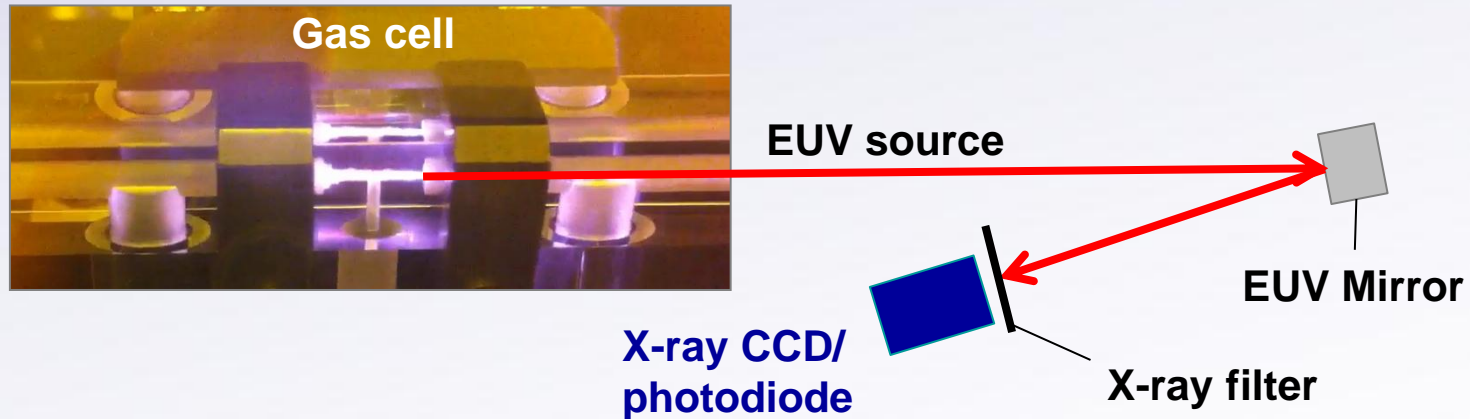
FST EUV040

FST

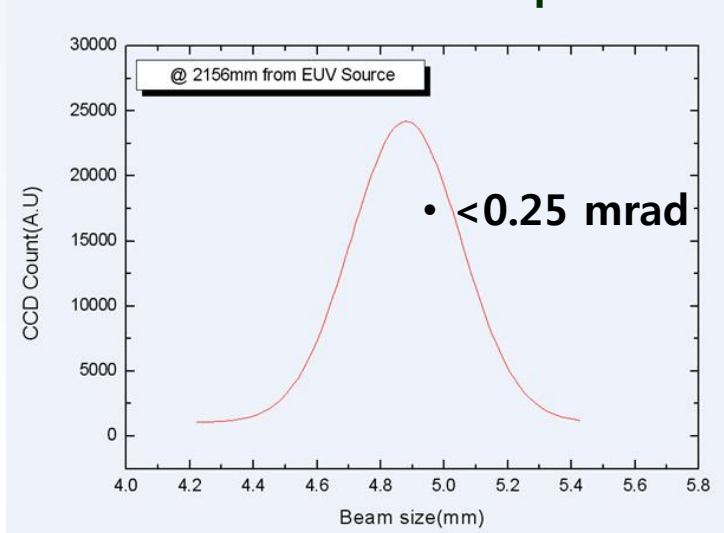


- FST(Fine Semitech Co., Ltd.) developed the coherent EUV source by using high-order harmonic generation
- Samsung and FST characterized the properties of the source together

EUV Power and Divergence Results

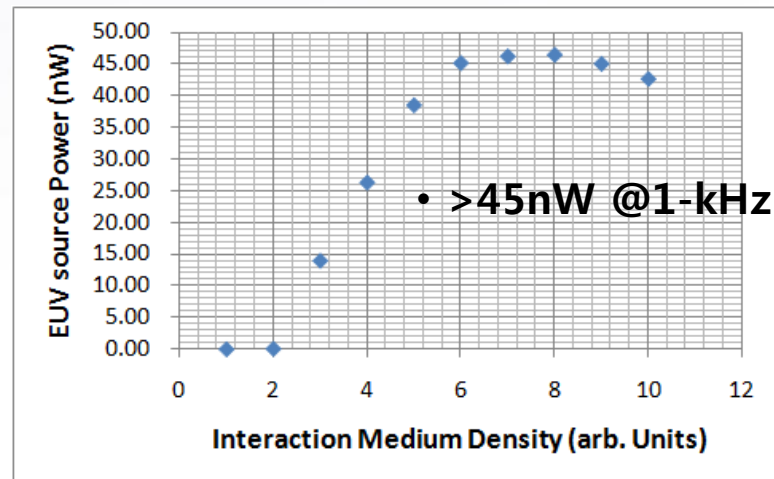


▪ Far-field EUV beam profile



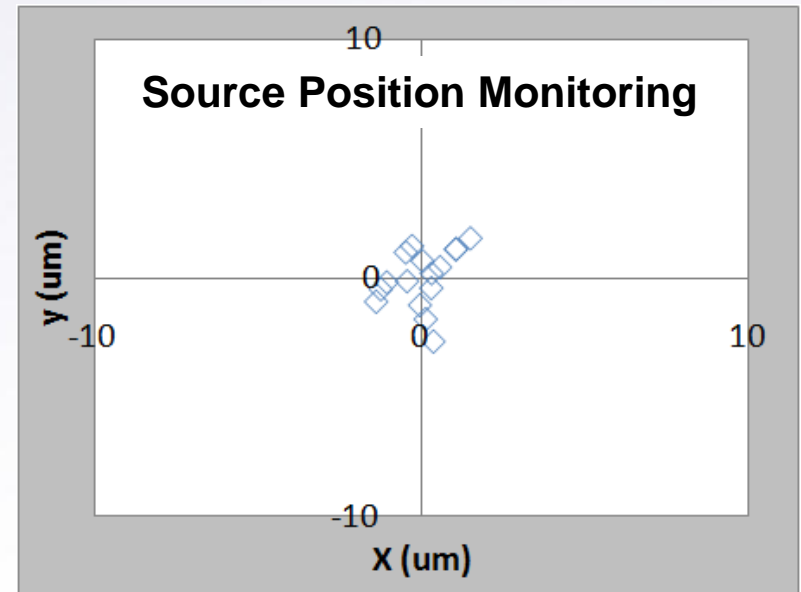
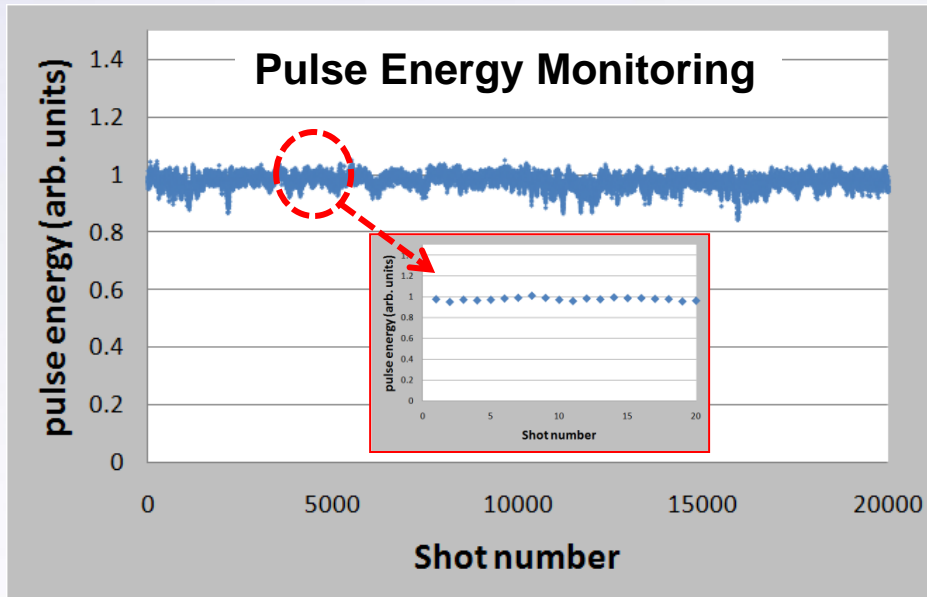
→ Lowest divergence using self-guiding techniques

▪ EUV power from x-ray photodiode (IRD)



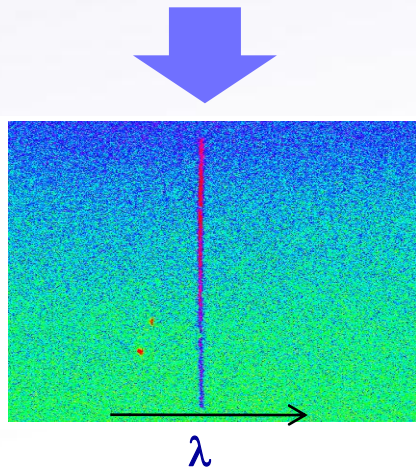
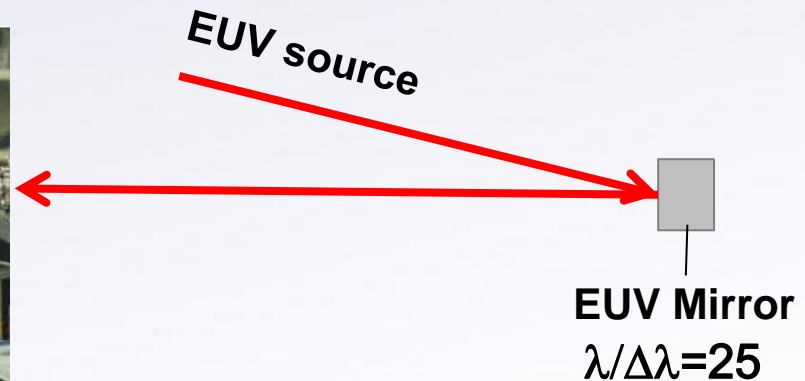
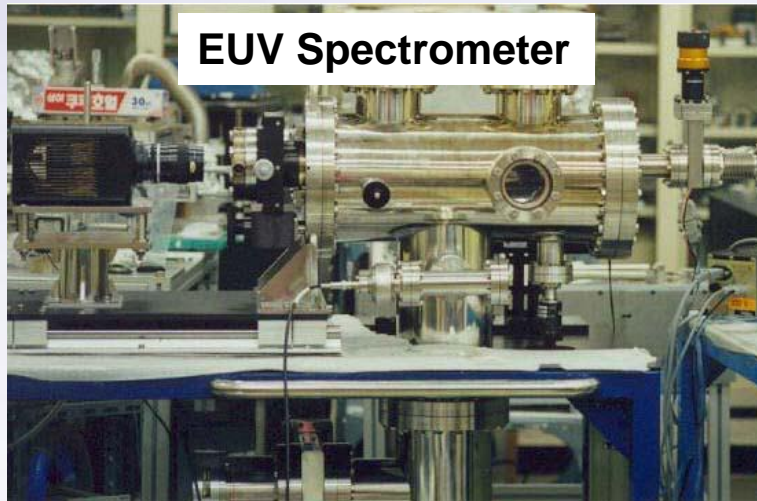
● Brightness: >182 W/mm²/sr

Shot-to-Shot Energy & Position Stability Results

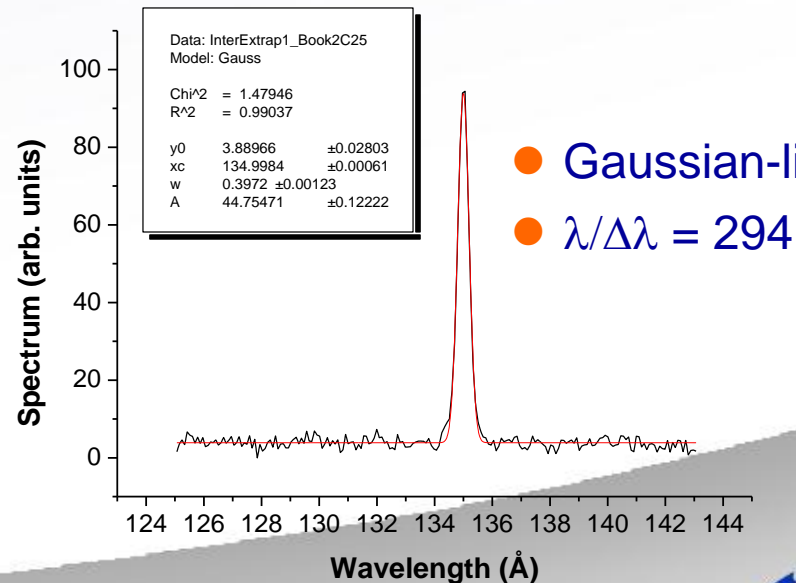


- Shot-to-shot energy stability: $\sigma = 2.3\%$ (pulse width < 50 fs)
- Shot-to-shot source position stability: $\sigma_{x,y} < 1.2 \mu\text{m}$, Range $< 4.3 \mu\text{m}$

EUV Spectral Bandwidth Results

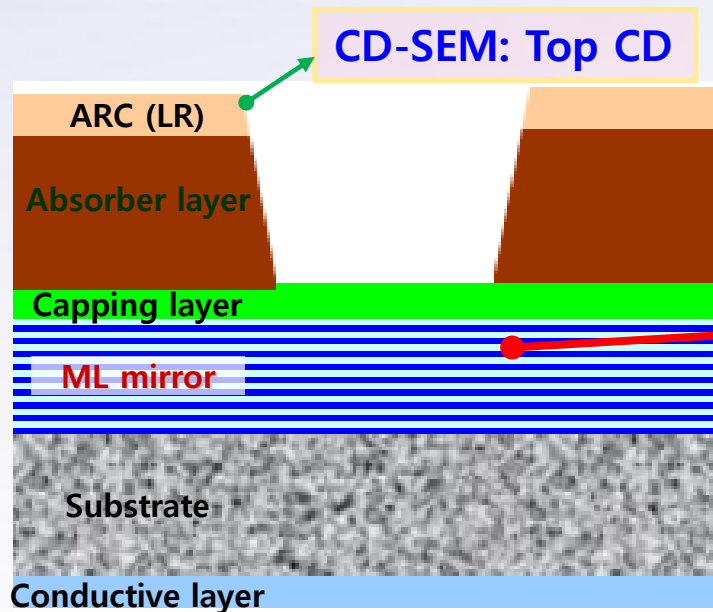


→ Narrow bandwidth using coherent control techniques



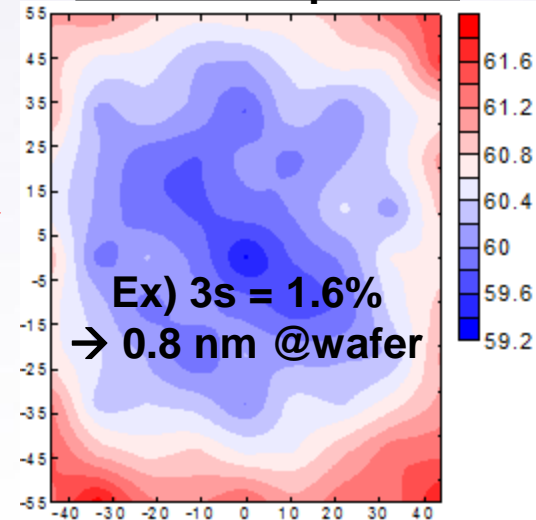
Needs an Actinic CD Measurement Tool

▪ 3-D Mask Effects



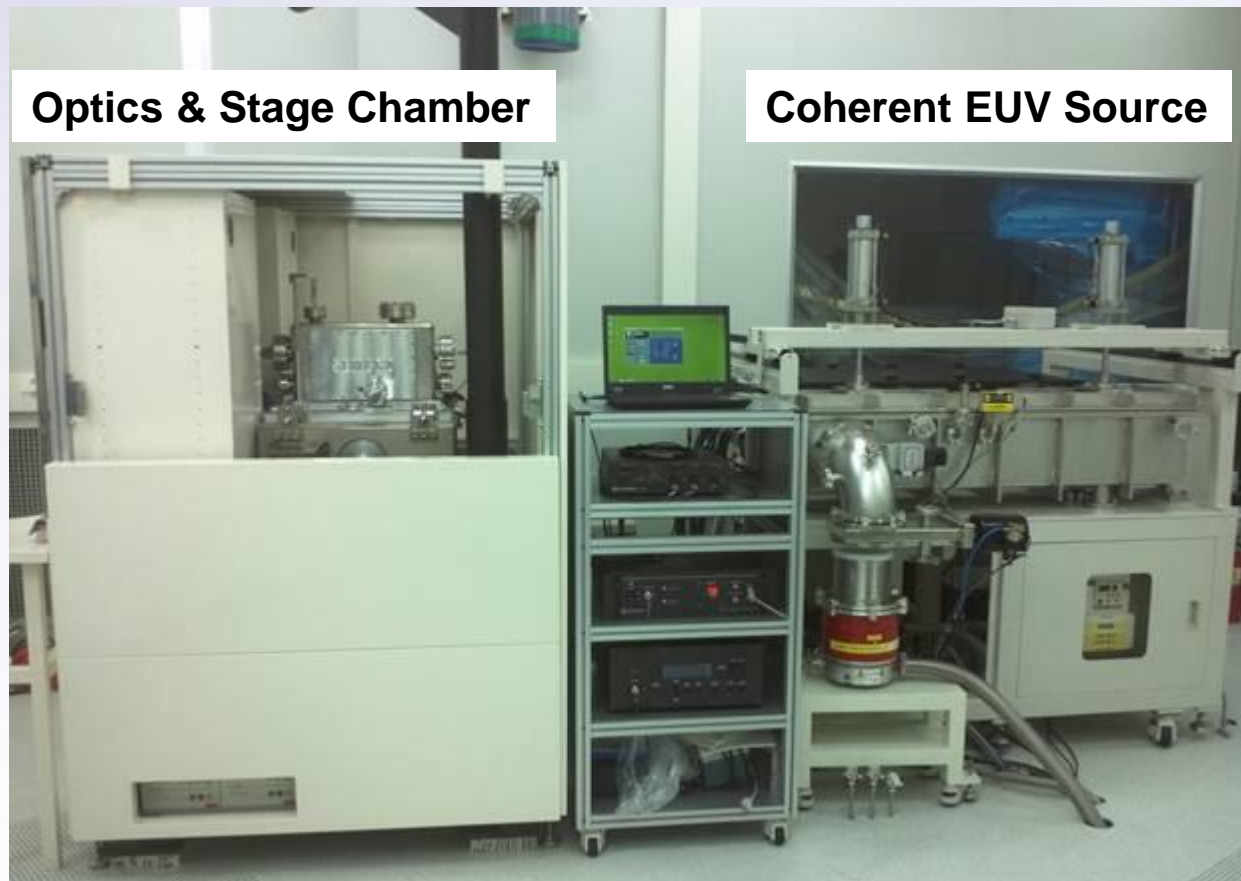
▪ Multilayer Effects

ML Reflectance Uniformity after mask process



- The only actinic CD tool (AIMS or CSM) can measure the integration of 3D mask and ML effects
- CSM (coherent scattering microscopy) is the best actinic CD-metrology solution for mask CD uniformity control with advantages of high throughput and superior repeatability

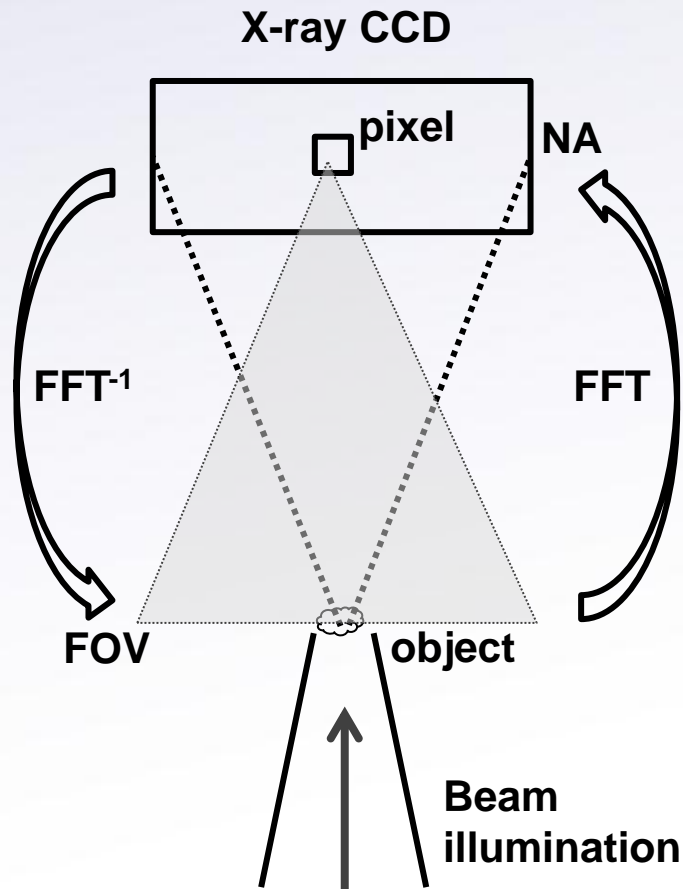
Stand-Alone CSM Using Coherent EUV Source



- The CSM using the coherent EUV source has built at Hanyang university
- The system measures field spectrum up to NA0.5 (4X wafer scale)
- Aerial image is reconstructed using field spectrum and iteration algorithm

Illumination & Coherence Conditions For CSM

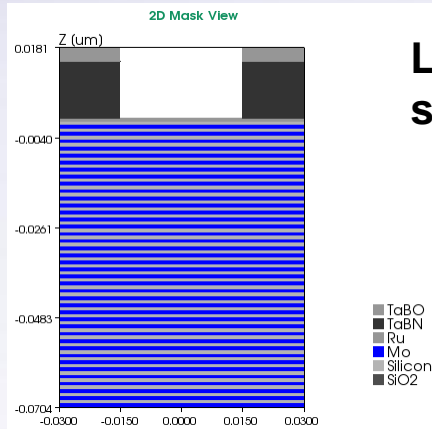
- Image reconstruction conditions:



1. Oversampling ratio(=FOV/beam size >> 2
 - pixel size of 13.5 μm \rightarrow FOV = 220 μm
 - beam size at sample: <2 μm
 - ratio = 110 (OK)
2. Fully spatially coherent beam (OK)
 - intrinsic property of high-order harmonic
3. Temporal coherence length > 0.25 μm
 - $L_{\text{coh}} = \lambda^2 / \Delta\lambda = 4 \mu\text{m}$ (OK)
4. SNR determined by shot noise, electrical noise, and flare (?)

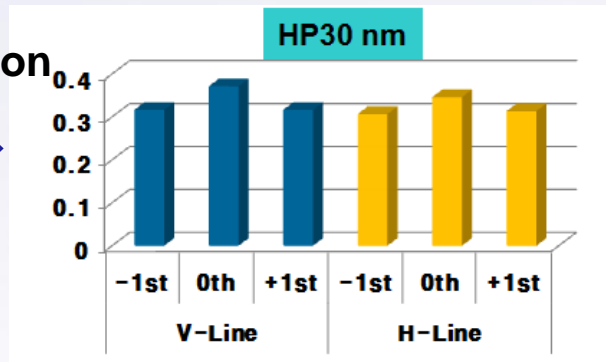
Application #1: CSM as a Scatterometry

Mask model

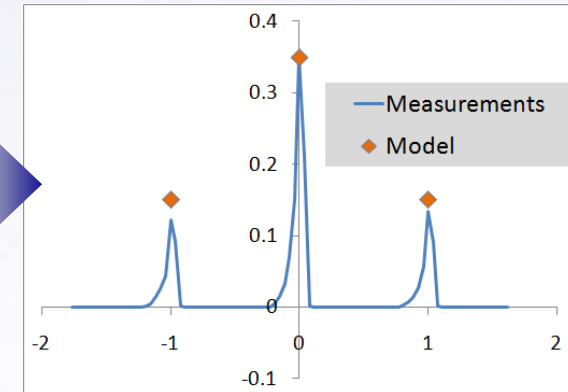


Litho.
simulation

Field Spectrum vs. CD library generation

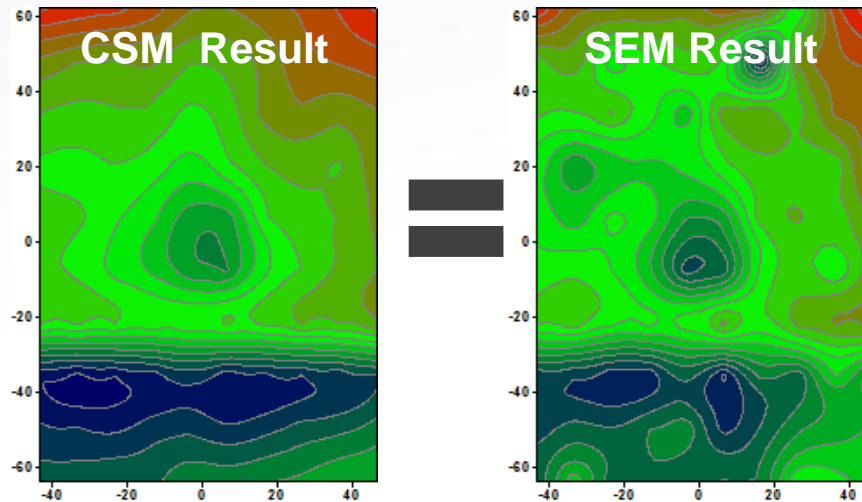


Fitting library to CSM data



< 30 msec / image

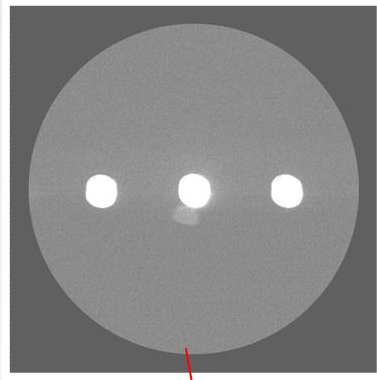
EUV Mask CD Uniformity Map



- CSM result shows very good correlation with SEM measurements

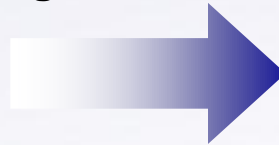
Application #2: CSM as an Aerial Image Measurement Tool

Measured field spectrum



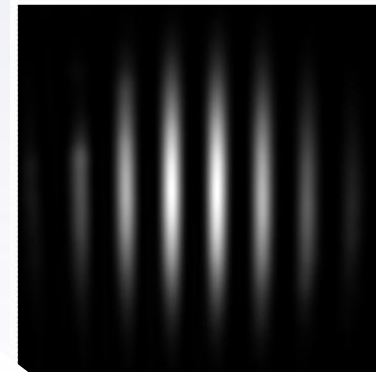
0.45 NA (4x wafer scale)

1. Phase retrieval using HIO algorithm



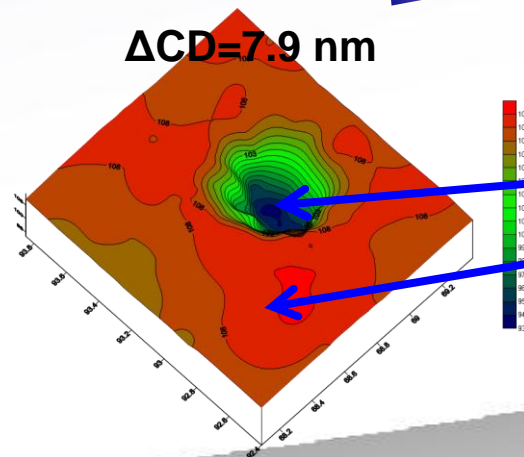
2. Applying illumination Kernel(NA & σ)

Reconstructed Aerial Image



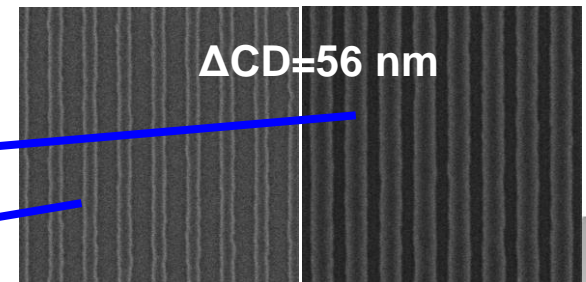
< 5 sec / image

Reconstructed CD
uniformity map for 88 nm
L/S pattern under
 $NA=0.25$ & $\sigma=0.8$ exposure
condition
after 3 hr exposure at
Pohang acceleration system



$\Delta CD=7.9$ nm

CD SEM Results



$\Delta CD=56$ nm

Summary

- We introduce a coherent EUV source in the area of EUV mask metrology
- Samsung characterized the coherent EUV source from FST and applied it to CSM at Hanyang university
- The summarized performance of EUV source as follow:
 - EUV source power: >45 nW @1-kHz repetition rate
 - Beam divergence : <0.25 mrad
 - Brightness: >182 W/mm²/sr
 - Spectral bandwidth: $\lambda/\Delta\lambda = 294$
 - Shot-to-shot energy stability: $\sigma = 2.3\%$ (pulse width < 50 fs)
 - Source position stability: $\sigma_{x,y} < 1.2 \mu\text{m}$, Range < 4.3 μm
 - Debris-free process of laser-gas interaction
- The application of this source to CSM makes it dispensable of collector and monochromator.
- The possibilities of stand-alone CSM using the source as an EUV scatterometry and aerial image measurement tool were demonstrated